THE TIME COURSE OF MEMORY FORWARD AND DOWNWARD DISPLACEMENTS OF CONTINUOUS MOVING TARGETS

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Abstract

When people are instructed to locate the vanishing position of a horizontally moving target, both forward (in the direction of motion – M-Displacement) and downward (in the direction of gravity – O-Displacement) errors of localization typically occur. Though several determinants of those errors have been ascertained, little is known regarding their time course. The present study attempts to fill this gap. Horizontally moving targets with varying velocities were presented and participants instructed to locate their vanishing position, either via a mouse or a pointer (on a touch screen), after a variable imposed time delay. Outcomes revealed an overall inverted-L shape of the errors trajectory as a function of time delay in the mouse, but not in the pointer condition. These findings are discussed with a link to the "straight-down belief" and what has come to be known as the "road-runner physics".

When a horizontally moving target which suddenly disappears is presented to human observers instructed to locate its vanishing location, a systematic trend to indicate a point displaced forward in the direction of motion is typically observed. Originally reported by Freyd and Finke (1984), the phenomenon was suggested to reflect an analogical internalization of physical dynamic properties, such as *momentum* (the quantity of motion) and *inertia* (the tendency to maintain it), and entitled accordingly as *Representational Momentum* (RepMo).

The first studies of RepMo relied on implied motion of the stimuli and on a mnesic probe methodology (same-different paradigm) to assess mislocalisation errors. In partial agreement with the proposed analogy, it was found that RepMo's magnitude increased proportionally with implied velocity (Freyd & Finke, 1985), that it was permeable to cognitive influences (conceptual effects on RepMo, e.g., as a result of manipulating the object's identity; Reed & Vinson, 1996), and that it emerged even for static pictures implying movement (e.g., frozen action photographs; Freyd, 1983) and for non-visual intensive continua (Brehaut & Tipper, 1996).

With the introduction of both smooth moving stimuli and behavioural localization measures (e.g., using a computer mouse; Hubbard & Bharucha, 1988; see also Hubbard, 2005) not only were most of those effects replicated as other related phenomena made their entrance in the literature, such as *Representational Gravity* (e.g., Hubbard, 1990, 1995, 1997; see below). However, little is still known regarding the temporal course of the *dynamic representations* assumed to underlie these effects.

The Time Course of RepMo

Following on the momentum analogy, Freyd and Johnson (1987) derived predictions for the time course of RepMo based on a physical model of momentum. Basically, RepMo's magnitude was predicted to increase with time after the target's disappearance, as if the dynamic representation kept its own "motion" despite the absence of physical movement.

This result was in fact obtained when the retention interval between the target's disappearance and the presentation of the mnesic probe was systematically varied. Moreover, RepMo's magnitude peaked at a retention interval of about 300 milliseconds, after which it decreased.

However, a null effect of the time course when eye movements were constrained was reported by Kerzel (2000), supporting a low-level view of RepMo. Taken at face value, this result undermined the Freyd and Jonhson's (1987) interpretation of the temporal evolution of dynamic representations; accordingly, no further attempts were made at ascertaining their time course.

Given the later finding that constraining oculomotor behaviour has no bearing upon RepMo's when a motor localization paradigm is employed (e.g., using a computer mouse) (Ashida, 2004; Kerzel, & Gegenfurtner, 2003), it actually remains to be seen whether a RepMo's time course can be established with such response modalities. Moreover, besides the usual forward displacement (*M-Displacement*; see figure 2, panel A), an additional displacement effect is typically found when localization responses are employed – the so-called *Representational Gravity* or tendency to judge the vanishing point as displaced downwards (e.g., for horizontally moving targets, in a direction orthogonal to motion: *O-Displacement*; Hubbard & Bharucha, 1988; Hubbard, 2005). No reported data on the time course of this downward displacement are available to date; and yet, uncovering the time course of *Representational Gravity* might be instrumental in highlighting not only the nature of this specific phenomenon as more generally the dynamics of the visual representation of moving objects.

The present study is a first attempt at filling these gaps. Smooth moving targets were presented to observers required to behaviourally locate its vanishing position after an imposed variable time delay, thus allowing the simultaneous measurement of *M* and *O* displacements over a range of retention times.

Method

Participants. 48 students (7 M; 41 F) at the University of Coimbra participated in the experiment in exchange for course credits. All had normal or corrected to normal vision and were unaware of the purposes of the study.

Stimuli. A set of computer animations (.avi type) portraying a moving black square with 30 pixels side (target) that emerged from either the left or the right edge of the screen and travelled horizontally (along the vertical centre of the screen) across a white background. The targets moved at a steady speed of 180, 300, 420 or 540 px/s (pixels per second) and suddenly vanished after covering a total distance of 536, 593 or 650 pixels.

Design and procedure. The experiment obeyed a factorial 4 (velocity) × 3 (distance) × 5 (retention time) × 2 (direction) × 5 (replications) repeated measures design, with response modality (mouse or pointer) as an additional between-subjects variable. Trials were randomized on a per-subject basis. Participants sat at about 60 cm from the screen with neither eye- nor head-movements restrictions, though they were required to maintain a steady posture for the entire duration of the experiment. They were instructed to attend to the target's motion until it disappeared. After an imposed delay of 0, 150, 300, 450 or 600 milliseconds, they had to locate the target's last seen position (referring to the target's geometrical centre), using either a wireless mouse which controlled a cross-shaped cursor or a softpoint pen (pointer) to directly touch the screen (touch sensitive). The end of the retention interval was signalled by an audible *beep* (pointer condition) or by the appearance of the cursor on the

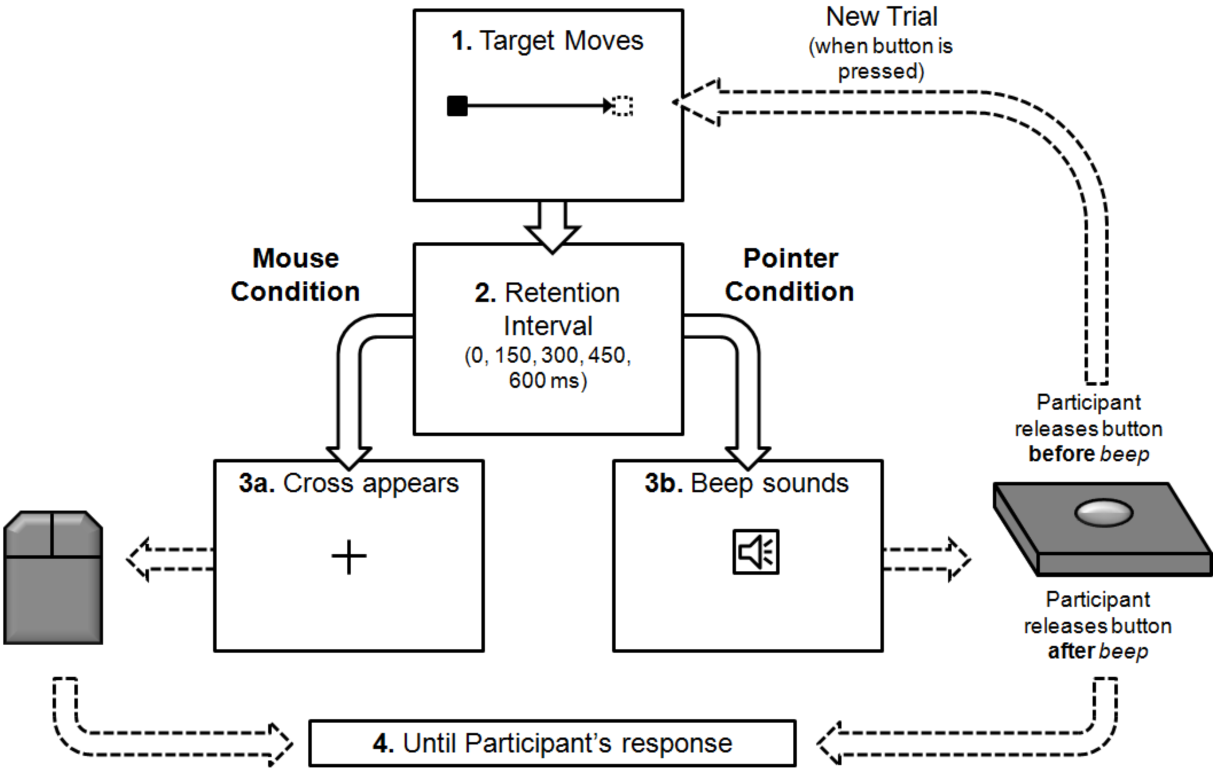

Figure 1 – Schematic representation of the experimental setting.

screen (mouse condition). To ensure that no hand or arm movements were performed during the retention intervals, trials where anticipated responses occurred were repeated. For that purpose (see figure 1), the motion of the cursor was continuously monitored during the retention intervals in the mouse condition. In the pointer condition, the hand holding the softpoint pen to be used for response was made to rest on a button of a response box at the beginning of each trial. This button was to be kept pressed until the *beep* signalling that a response could be given was heard. At that point, participants were allowed to raise the hand, thus releasing the key, and proceed to touch the desired location on the screen. In case of undue release of the key, the current trial was selected to be repeated later on. Stimuli presentation, trials randomization and response recording were performed via *Super Lab 4.0* on a personal computer equipped with a wireless mouse and a touhscreen with resolution of 1024×768 pixels and a refreshing rate of 60Hz.

Results

For each trial, the difference between the *x* coordinate of the target's geometrical centre on the last frame of the animation and the *x* coordinate of the participant's response was computed, providing a measure of *M-displacement*. Likewise, the difference between the corresponding *y* coordinates was used as a measure of *O-displacement*. These data (averaged across replications) were subjected to two mixed ANOVAs, one for each displacement component (*M* and *O*) and with response modality as a between-subjects factor. Greenhouse-geisser correction for the degrees of freedom was used whenever the sphericity requirement could not be assumed.

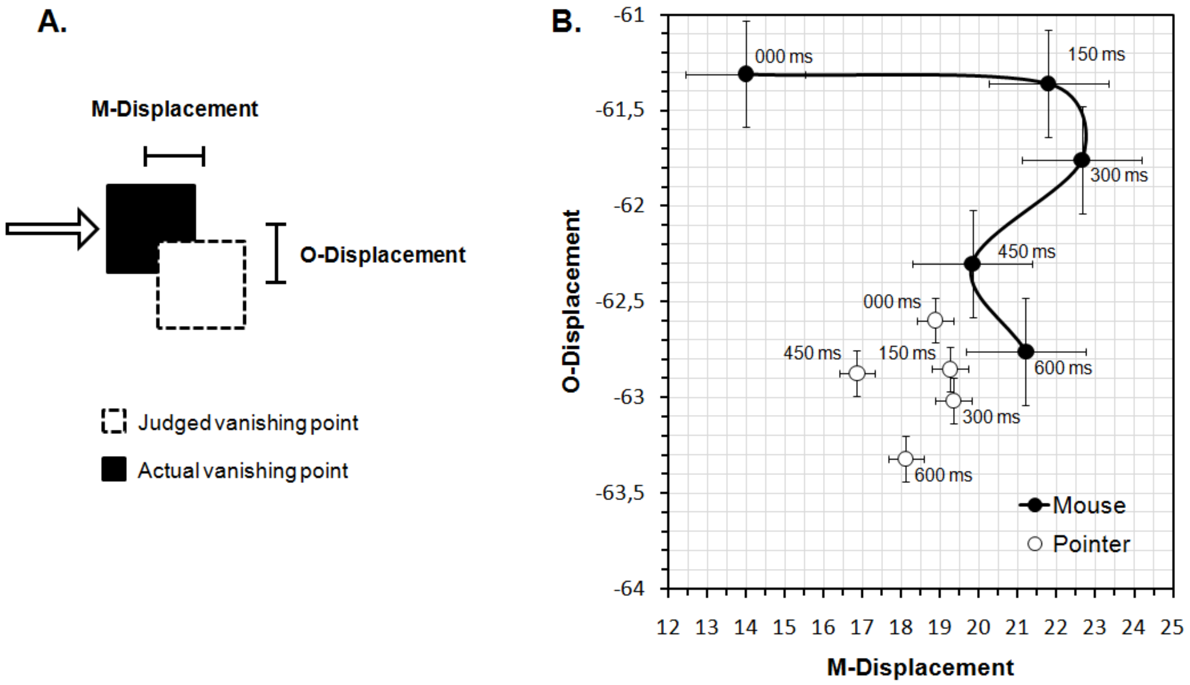

Figure 2 – *Panel A:* schematic representation of the M (motion-direction) and O (orthogonal to motion-direction) components of mnesic displacement. *Panel B:* bi-dimensional (M and O displacement as the axes-system) representation of the data obtained for the mouse (closed circles) and the pointer (open circles) conditions across different retention times.

Regarding *M-displacement*, statistical analysis disclosed a significant effect of both target's velocity, $F(1.793, 82.497) = 49.393$, $MSE = 935.468$, $p < .05$, $\eta^2_p = .52$, and retention time, $F(2.46, 113.142) = 12.311$, $MSE = 517.483$, $p < .05$, $\eta^2_p = .21$. Response modality had no significant main effect ($p > .05$), but interacted significantly with retention time, $F(2.46, 113.142) = 11.271$, $MSE = 517.483$, $p < .05$, $\eta^2_p = .2$. Separate ANOVAs for each modality revealed a significant effect of retention time for the mouse condition, $F(2.922, 67.198) = 19.393$ $MSE = 486.331$, $p < .05$, $\eta^2_p = .46$, but a null effect for the pointer condition, $p > .05$.

As for *O-displacement*, target's velocity had no significant effects, $p > .05$, but retention time showed a significant main effect, $F(4, 184) = 7.432$, $MSE = 28.289$, $p < .05$, $\eta^2_p = .14$. The ANOVAs performed separately for each modality revealed a significant main effect of retention time in the mouse condition, $F(2.765, 63.584) = 10.924$, $MSE = 29.778$, $p < .05$, $\eta^2_p = .32$, but a null effect in the pointer condition, $p > .05$.

Given that each participant's response provides a location on a 2-D space, the data can be represented in a displacement "map" with *M* and *O* components as the *x* and *y* coordinates, respectively. This would provide an image of the 2-D "trajectory path" covered in memory by the target as a function of time. As can be seen in Figure 2 (Panel B), the points corresponding to different retention intervals in the pointer condition (open circles) tend to cluster together around a similar value. On the other hand, a patterned course of target's mislocalisation as a function of time can be seen in the mouse condition. This time course of the localization error can be sensibly described as a two stage process: for the first 300 milliseconds, the target's representation "moves" forward with virtually no vertical displacement; after 300 milliseconds, it appears to "fall" down, with no further increment in its horizontal position.

Discussion

The obtained results show that retention time has a different effect upon the M and O components of mnesic displacement, dependent moreover on the response modality. As for the pointer condition, no significant effects of time were observed. This concurs with the previous finding (De Sá Teixeira, Oliveira & Amorim, 2010) that direct response modalities (e.g., using a touchscreen) are more impervious than indirect ones to variables otherwise relevant to RepMo (conjecturally, due to the recruiting of the perception-for-action visual stream; Milner & Goodale, 1995). As for the mouse condition, an inverted (vertically) and mirrored L-shape appears to fit overall the 2-D trajectory of the mislocalisaton error.

It should be noticed at this point that the stimulus is no longer present during the retention interval. The mnesic displacement of the moving target should thus be directly reflecting the inner dynamic properties of its representation.

The observed time course of the mislocalization error is compatible with an *impetus*-like implicit physics. During the first 300 milliseconds no downward displacement occurs – as if an object animated by some imparted impetus resisted gravity while the impetus remains active. At some point, however – the moment the impetus dissipates – the object becomes subjected to the gravitational pull alone and adopts an overall straight down course. Such implicit conceptions of the movement of projectiles have been reported in studies of naive physics and were popularly labelled as *road-runner* physics, after the well known cartoon (see, e.g., Gentner, 2002). Similar principles were actually suggested to govern projectiles' motion by mediaeval scholars (like Jean Buridan, 1300-1358; see McCloskey, 1983), and have been used later as modelling tools by XVIth century cannoneers (cf. the ballistic trajectories devised by Paulus Puchner in 1577; see Hecht & Bertamini, 2000).

This noticed convergence between results arising from localization responses, on the one hand, and from intuitive physics, on the other, strengthens the notion that displacement errors like *Representational Momentum* (Freyd & Finke, 1984) and *Representational Gravity* (Hubbard, 1990, 1995, 1997) might eventually embody an implicit, impetus-like physics, expressing as well in pre-Newtonian epistemologies as in our daily reliance on dynamic representations.

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